WIRELESS MEASUREMENT OF SOIL MOISTURE AND TEMPERATURE WITH LPWAN TECHNOLOGY

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ABSTRACT

A Low Power Wide Area Network (LPWAN) is a type of wireless telecommunication wide area network designed to allow long range communications at a low bit rate among items (connected objects) such as sensors operated on a battery.

Firstround company was the commissioner of this thesis. The objectives of this thesis were to get know the sensor quality through working in the soil and by sending data into the Sigfox cloud, then receiving data through the smart devices and computer.

The goal of this project was to evaluate soil moisture by using several samples. Therefor a waterproof SHT-10 sensor was used to measure the soil moisture, temperature and water content in the soil.

Generally, to make this experiment, several measurements were used: a waterproof SHT-10 sensor, soil samples, a moisture container, a sensitive scale, a desiccator and an oven for drying.

My accomplishment with this project was to prove the average water content in the soil before and after drying. I also wanted to examine relationship between the soil moisture and temperature.

Keywords Relative humidity, soil moisture, temperature, Atmel ICE, Sigfox, LPWAN.

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1 INTRODUCTION

The commissioner of this thesis's project, Firstround company in Riihimäki operator in the field of accelerator services which are ideally suited for start-up companies and for all enterprises that want to grow and renew their business. In Firstround company's accelerator programme, they collaborate with client companies to define in detail plans and actions to achieve this. Its they assist the company to receive starting-phase financing and to develop its final products for the market.

Soils may be composed of a combination of solid materials, water and air. Three of these stages may occupy volume, only solid materials and water are considered to have weight.

Soil moisture and temperature measurements are among the most significant issues in various areas of applications such as instrumentation, automated systems, agriculture, climatology.

A soil moisture sensor is used for measuring the moisture, temperature and water content of soil. A soil moisture sensor is useful for the indication of the amount water content of a given soil sample. Expected values for soil moisture and temperature are often contingent upon the land cover type.

It has been shown that the association between soil moisture and temperature affect the intensity and incidence of extreme temperatures.

Water content in the soil can be determined by the difference in weight before and after drying a soil sample. The ratio of the mass of water present in a sample to the mass of the soil sample after it has been oven dried in 110 degrees to a constant weight.

2 DEFINITION OF HUMIDITY

2.1 Relative humidity in the air

Humidity refers to the presence of water in the air. There are two important terms when talking about humidity, namely “absolute humidity” and “relative humidity”. At the beginning we should know what absolute humidity is to know relative humidity. (Relative Humidity, 2018)

2.2 Absolute humidity

Absolute humidity is the amount of water vapor divided by the amount of air dry to a certain volume of air at a certain temperature. The hotter the air is the higher the absolute amount of water it can contain. (Absolute Humidity, 2018)

2.3 Relative humidity

Relative humidity means the proportion of the current the absolute humidity. The highest attainable absolute humidity depends on current temperature and pressure. Relative humidity is published in weather reports and mentioned in guidance for healthy indoor climate, for example.

Relative humidity is the ratio of water vapor in the air to what the air can carry from it at the same temperature and the same atmospheric pressure. It is calculated by the actual vapor density and the saturated vapor density or from the pressure of the water vapor and the actual water vapor pressure as follows:

$$Relative\ Humidity = \frac{actual\ vapor\ density}{saturation\ vapor\ density} * 100\% \tag{1}$$

$$Relative\ Humidity = \frac{water\ vapor\ pressure}{actual\ water\ vapor\ pressure} * 100\% \tag{2}$$

The units for vapor density are gm/m^3. For example, if the actual vapor density is 10 g/m^3 at 20°C and it is compared to the saturation vapor density 17.3 g/m3 at temperature 20 C, the relative humidity is:

$$R.H. = \frac{10g/m^3}{17.3g/m^3} * 100\% = 57.8\%$$

(3)

When relative humidity is 100%, the air is saturated with water vapor and cannot carry more. Clouds need the same proportion to form. Humans are affected by the air humidity, as the skin depends on the air to get rid of sweat in the form of water vapor, and thus cool the body and keep the temperature within the required range.

So, if the humidity is 100%, sweat will not evaporate into the air. As a result, we will feel more warmly than it actually is. If the relative humidity is low, we will feel cooler because the sweat will evaporate easily.

For example, if the air temperature is 30°C and relative humidity is 0%, the temperature will look like 27°C. If the temperature is 30°C, and the relative humidity is 100%, we will feel as hot as 33°C. (Relative Humidity, 2018)

3 DEWPOINT

When the air is gradually cooled while maintaining the moisture content the relative humidity constant will increase to 100%. This temperature, where moisture content in the air will saturate the air, is called the dew point. if the air is cooled further, some of the moisture will dense. As in illustrated in Figure 1.

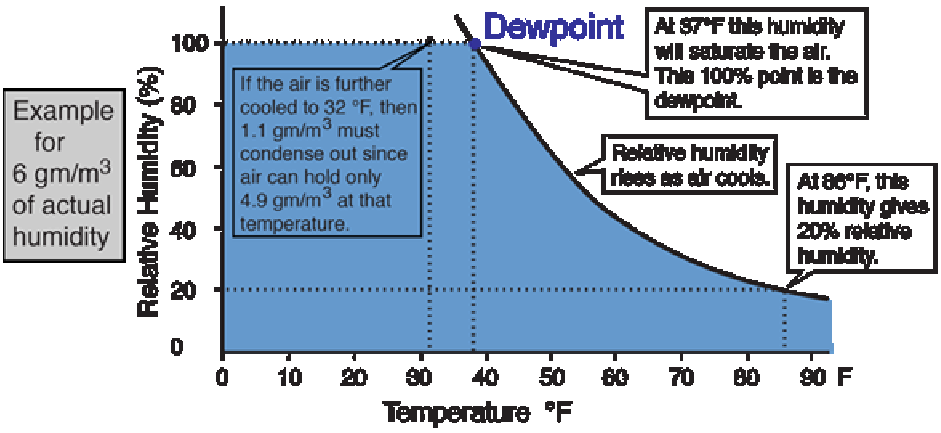


Figure 1. (Relative Humidity, 2018)

4 SATURATED VAPOR PRESSURE

The process of evaporation in a closed container will proceed until there are as many molecules returning to the liquid as there are escaping. At this point the vapor is said to be saturated, and the pressure of that vapor (usually expressed in mmHg) is called the saturated vapor pressure. As in illustrated in Figure 2.

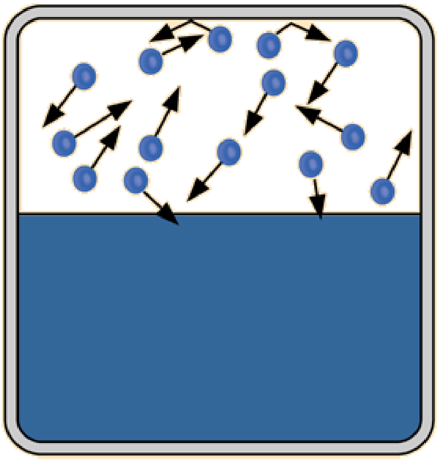


Figure 2. (Saturated Vapor Pressure, 2018)

Molecular kinetic energy is greater at elevated temperatures, more particles can escape from the surface and saturated vapor pressure is higher. If the liquid is open to air, water vapor is partially compressed with other air components. The temperature at which the vapor pressure is equal to the atmospheric pressure is called the boiling point. (Vapor Pressure, 2018). As in illustrated in Table 1.

Table 1. (Water Vapor and Vapor Pressure, 2018)

Temp (°C)	Temp (°F)	Saturated Vapor Pressure (mmHg)	Saturated Vapor Density (gm/m^3)	Temp (°C)	Temp (°F)	Saturated Vapor Pressure (mmHg)	Saturated Vapor Density (g/m^3)
-10	14	2.15	2.36	40	104	55.3	51.1
0	32	4.58	4.85	60	140	149.4	130.5
5	41	6.54	6.8	80	176	355.1	293.8
10	50	9.21	9.4	95	203	634	505
11	51.8	9.84	10.01	96	205	658	523
12	53.6	10.52	10.66	97	207	682	541
13	55.4	11.23	11.35	98	208	707	560
14	57.2	11.99	12.07	99	210	733	579
15	59	12.79	12.83	100	212	760	598
20	68	17.54	17.3	101	214	788	618
25	77	23.76	23	110	230	1074.6	...

30	86	31.8	30.4	120	248	1489	...
37	98.6	47.07	44	200	392	11659	7840

4.1 Evaporation

Evaporation is a physical process in which molecules are transformed from liquid to gaseous by heat. The process occurs only on the surface between liquid and gas, which is the opposite of condensation. This process is called the saturated vapor pressure. (Vapor Pressure, 2018). As in illustrated in Figure 3.

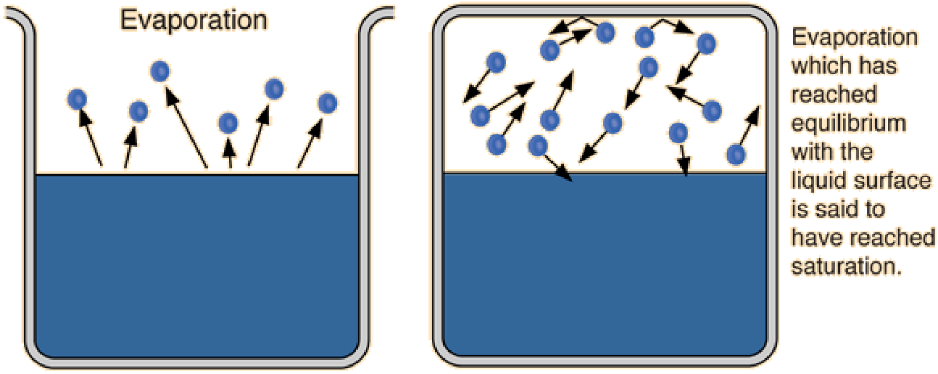


Figure 3. (Vapor Pressure, 2018)

Surface water evaporates on the surface of the earth with sunlight, helping to maintain moisture in the atmosphere. These oceans, rivers and lakes provide about 90 % of total moisture, while the process of leaching plants contribute 10 %, while evaporation cannot occur when the humidity in the atmospheric is 100 %. (Vapor Pressure, 2018)

5 MOISTURE CONTENT

Soil holds water in the form of moisture, which can be absorbed by a plant for an extended period. The chemical weathering process allows soil metals to continue to undergo changes in their mineral, chemical and physical properties, known as soil formation processed. (Moisture Content - Cornell Composting, 2018).

The chemical weathering of the soil minerals results in the release of certain nutrients such as potassium K, sodium Na, calcium Ca, manganese Mn, magnesium Mg and iron Fa from different mineral crystals to the water solution (soil solution) in the form of dissolved ions, which make it available to the plant. (Moisture Content - Cornell Composting, 2018).

The moisture content, which is retained in the soil, affects other physical properties such as bloating, shrinkage, especially in clay soil, containing a substantial proportion of montmorillonite, and the extent of their trafficability. (Moisture Content - Cornell Composting, 2018).

Soil water is present in equilibrium with the air of the soil also located within the soil pores and soil air is also necessary to breathe the roots of developing plants. A change in soil water and soil air usually occurs and reciprocally affects within the soil pores.

Soil moisture content is defined as the amount of moisture or water present within the soil pores and around the surface of the soil granules attributed to the dry mass of soil that is:

$$Moisture\ content\ of\ soil = \frac{Moisture\ mass\ in\ the\ soil}{Soil\ mass\ completly\ dry}$$

$$= \frac{Wet\ soil\ mass - Soil\ mass\ completly\ dry}{Soil\ mass\ completly\ dry}$$

(4)

In this case, it is defined as mass moisture content (calculated based on dry soil mass).

We can express soil moisture content based on size:

$$Moisture\ content\ volumetric = \frac{The\ volume\ of\ water\ in\ the\ soil}{Total\ soil\ size}$$

(5)

In the installation industry, we must agree to report wet moisture content (or total weight), as the formulas below indicate. (Moisture Content - Cornell Composting, 2018).

Calculation of moisture % for each of the materials that we plan for compositing.

- Weight of empty container and record value.
- Weight of material into container and record value.
- Taking a sample of the soil and drying it at 105°C in the oven for 24 hours. Where the heat converts the water in the soil to water vapor out of the sample and thus it becomes completely dry (free from all forms of moisture).
- Reweigh the sample subtract the weight of the container and determine the moisture content using the following equation:

  $M_n = ((W_w - W_d)/W_w)$ x 100%

(6)

In which:

M_n = moisture content (%) of material n

W_w = wet weight of the sample

W_d = weight of the sample after drying.

5.1 **Requirement tools**

- Moisture container
- Sensitive balance
- Soil sample
- Electric oven for drying

For example, that we weight 10 g of grass clippings (W_w) into a container a 4 g and that after drying the container in addition to the weight 6.3 g. Subtracting out the 4-g. Container weight leaves 2.3 g as the dry weight (W_d) of your sample. Moisture will be:

$M_n = ((W_w - W_d)/W_w) \times 100$

$= ((10 – 2.3) / 10) \times 100$

= 77% for the grass clippings

5.2 **Working method**

- The moisture container is weighed empty and the weight is recorded value (Q_1).
- Put a quantity of soil to estimate moisture content in the moisture container shall be placed and the weight process shall be carried out again (moisture container weight + wet soil) and recorded value (Q_2).
- Place the moisture container in a 105°C electric oven and closed the oven and leave the sample drying for 24 hours or until the weight is stable.
- Remove the moisture content after drying and weight on a sensitive balance (moisture container weight + soil completely dry) and record the value Q_3.
- Calculate soil moisture content from the following equation:

  Q_1 = The moisture container weight is empty

  Q_2 = Moisture container weight + wet soil sample before drying

Q_3 = Moisture container weight + the soil sample is completely dry after drying

Q_2 - Q_1 = Wet soil sample weight

Q_3 - Q_1 = The weight of the soil sample is completely dry

Moisture weight in the sample = Wet soil sample weight - The weight of the soil sample is completely dry: (Moisture Content - Cornell Composting, 2018).

(7)

= (Q_2 - Q_1) – (Q_3 - Q_1)

= Q_2 - Q_3

$$Moisture\ content\ of\ mass = \frac{Moisture\ weight\ in\ the\ sample}{Weight\ of\ the\ soil\ completely\ dry}$$

$$Moisture\ content\ of\ mass = \frac{Q_2 - Q_3}{Q_3 - Q_1}$$

(8)

Choose our moisture target fertilizer mixture. Most of the literature recommended a moisture content of 50% -60% by weight for optimal planting conditions?

Next steps calculate the relative quantities of substances that must be combined to achieve our moisture goal. The general formula for moisture is:

$$G = \frac{(Q_1\ x\ M_1) + (Q_2\ x\ M_2) + (Q_3\ x\ M_3) + \ldots}{Q_1 +\ Q_2 +\ Q_3 + \ldots}$$

(9)

In which:

Q_n = mass of material n (“as is”, or “wet weight”)

G = moisture goal (%)

M_n = moisture content (%) of material n

We can use this formula directly to calculate the moisture content of the mixture of materials, and try different combinations until we get results in a reasonable range

Use trial and error to determine what ratios to use for the mixture will work, but there is a faster way. For two articles, the general equation can be simplified and solved for the mass of the second article (Q_2) required to balance a certain mass of the first article (Q_1). Note that the moisture objective must be between the moisture contents of the two materials that are mixed. (Moisture Content - Cornell Composting, 2018).

$$Q_2 = \frac{(Q_1 \; x \; G) - (Q_1 \; x \; M_1)}{M_2 - G} \tag{10}$$

For example, suppose we want to compost 10 kg grass clippings (moisture content = 77%). To achieve our moisture objective of 60% for the compost mix, the required leaves mass is calculated (moisture content = 35%):

$$Q_2 = \frac{(Q_1 \; x \; G) - (Q_1 \; x \; M_1)}{M_2 - G}$$

= ((10 kg) (60) – (10 kg) (77) / (36 – 60)

= 6.8 kg leaves

Mixtures of three or more substances can also be solved in an analogous manner (although algebra is more complex), but for an accurate solution the quantities of all substances except one must be quantified. To find the mass of the third article (Q_3) in view of the first two masses ($Q_1 \; and \; Q_2$) as well as all three moisture contents ($M_1, M_2 \; and \; M_3$) and a goal G, solve: (Moisture Content - Cornell Composting, 2018).

$$Q_3 = \frac{(G \; x \; Q_1) + (G \; x \; Q_2) - (M_1 \; x \; Q_1) - (M_2 \; x \; Q_2)}{M_3 - G} \tag{11}$$

6 WATER CONTENT

Water content or moisture content is the amount of water contained in a substance, such as soil (called soil moisture), rocks, ceramics, crops or wood. Water content is used in a wide range of scientific and technical fields and is expressed as a ratio, which can range from 0 (completely dry) to the value of material porosity at saturation. It can be given based on volumetric or mass (gravimetric). (Water content, 2018).

6.1 Measurement

6.1.1 Direct methods

Water content can be measured directly using a known volume of materials, and drying oven. Volumetric water content θ is calculated by the volume of water V_w and the mass of water m_w:

$$V_w = \frac{m_w}{\rho_w} = \frac{m_{wet} - m_{dry}}{\rho_w}$$

(12)

Which in:

$m_{wet}\ and\ m_{dry}$ are the masses of the sample before and after drying in the oven;

ρ_w is the density of water. For materials that change in volume with water content, such as coal, the water content, u, is expressed in term of water of mass per unit mass of damp sample:

$$u = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

(13)

For wood, the convention is to report moisture content based on dry oven (i.e. typically drying the sample in the set oven at 105℃ for 24 hours). In wood drying, this is an important concept. ("Water content", 2018)

7 HUMIDITY OR MOISTURE MEASUREMEN TECHNOLOGIES

7.1 Measurement of humidity

Traditionally the measurement of humidity in the air is based on a device known as the humidity meter (Hygrometer). It contains a pen that is used as an indicator to draw the moisture rate that the device sets while working on moisture measurement. It is accompanied by a measurement table to determine the difference between different humidity rates.

7.2 **Methods of moisture measurement**

7.2.1 Psychrometer

It is a device consisting of two thermometers, one of which is dry and the other is wet. Humidity is measured by comparing the two temperature levels indicated by the two scales. This is one of the simplest methods used to measure humidity. (Psychrometer, 2018)

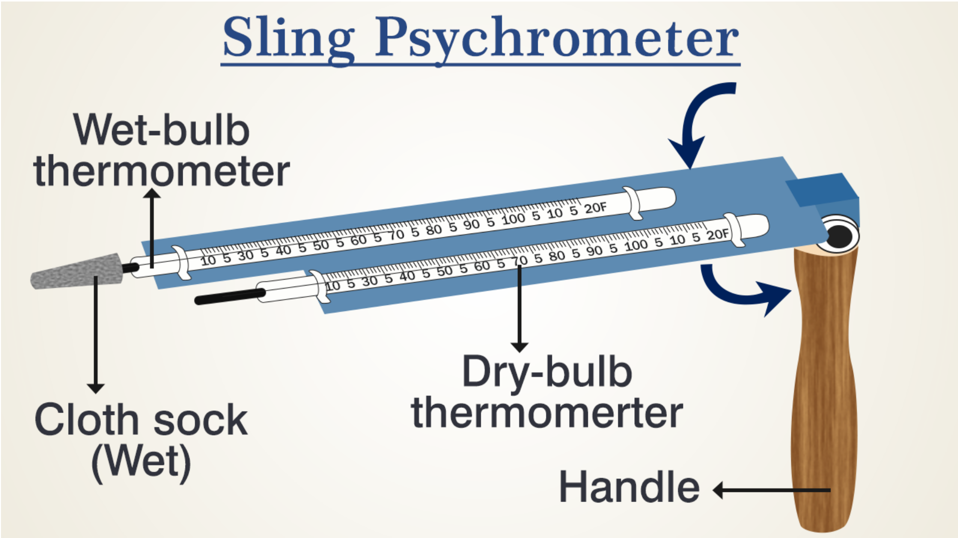


Figure 4. (Psychrometer, 2018)

7.2.2 Hygrometer

This device is made up a set of hair follicles that may be human or may be for a horse. Because the hair expands when the moisture increases and shrinks when it is low, a feather is installed at the end of these follicles moving in front of a ruler with numbers from 0 to 100. Hygrometers play a big part in saunas, greenhouses, industries, incubators, and, most importantly, indoor plant care. (What is Hygrometer - Definition from Maximum Yield, 2018)

Figure 5. (Hygrometer, 2018)

7.2.3 Hygrograph

The hygrograph uses the change of the length of human hair or synthetic fibers depending on the moisture contained in the air.

The special treatment of the hair is the reason for the very low response time, even in case of very low temperatures. For this reason, hair-hygrographs are preferred for outdoor measurements. (Hygrograph | Theodor Friedrichs & Co, 2018)

Figure 6. (Hygrograph, 2018)

8 TEMPERATURE

Temperature is a measure of the amount of hotter or cooler thing, or scientifically it is the average kinetic energy of particles in the object. It is a type of energy associated with the motion, for example a glass of boiling water contains very active molecules, it moves very quickly and producing heat that can be felt by hand, unlike cold objects.

Scientists usually they are using water boiling temperature and freezing to compare the temperature of other materials. Note that the boiling point of water is 100 degrees Celsius, and the degree of freezing is 0 degrees Celsius. The temperature is also a measure of the average thermal energy of the material. Thus, they do not depend on the number of molecules of matter, which does not depend on their size.

The temperature of a small glass of boiling water is equal to the temperature of a large bowl of it, even if the pot is very large compared to the size of the glass. (Temperature Means in Science, 2018)

8.1 Temperature measuring instruments

8.1.1 RTD

RTD is Resistance Temperature Detectors are temperature sensors that contain a resistor that changes resistance value as its temperature changes. They have been used for many years to measure temperature in laboratory and industrial processes, and have developed a reputation for accuracy, repeatability, and stability. Most RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it. (RTD Sensor, 2018)

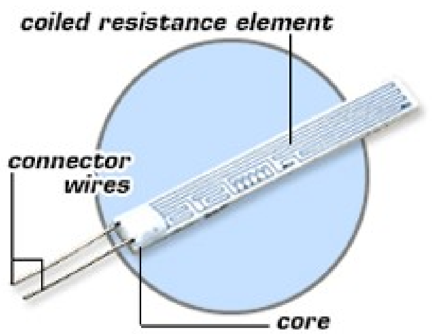


Figure 7. (RTD Sensors Resistance Temperature Detection, 2018)

8.1.2 PTC

PTC stands for Positive Temperature Coefficient. PTC thermistors are resistors with a positive temperature coefficient, which means that the resistance increases with increasing temperature. PTC thermistors are divided into two groups, based on the materials used, their structure and the manufacturing process. (PTC thermistor, 2018)

Figure 8. (PTC thermistor - Positive Temperature Coefficient, 2018)

8.1.3 Mercury thermometer

The meter consists of a glass cylinder at one end of which is a mercury tank. Temperature is determined based on the level of mercury in the cylinder. The idea of the scale depends on mercury expansion an elevated temperature and shrinkage at low temperature. The rest of the cylinder is filled with nitrogen or the air is drawn from it. (Mercury-in-glass thermometer, 2018)

Figure 9. (Temperature Sensors - CTG Technical Blog, 2018)

8.1.4 Radiation thermometer

The infrared thermometer is a thermometer that measures the heat through a portion of the heat radiation called black body radiation that radiates through the body to measure its temperature. The thermometer consists of a lens to focus on infrared radiation towards a detector that converts the radiation power to an electric signal that is displayed on the thermometer. (Infrared thermometer, 2018)

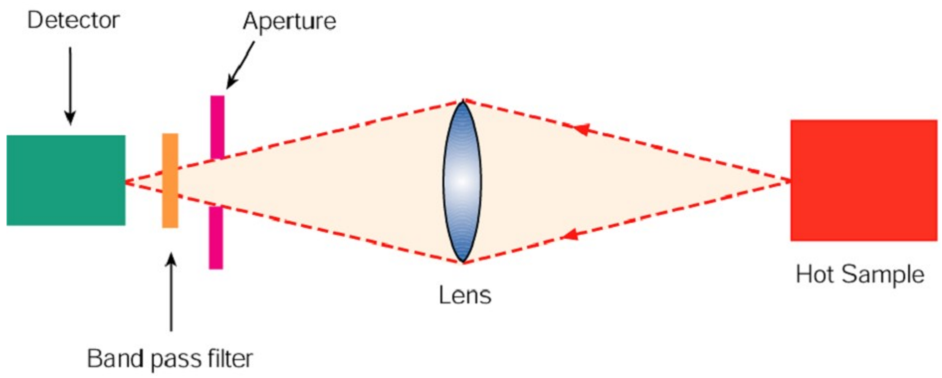


Figure 10. (Non-contact infrared radiation thermometers, 2018)

9 RELATIONSHIP BETWEEN TEMPERATURE AND RELATIVE HUMIDITY

The relative humidity of an area varies considerably during the day, although the amount of water vapor in the air remains the same. In such cases, relative humidity changes when temperatures rise or fall. Relative humidity may be higher in the morning, the air is unable to carry more water vapor than the amount it carried at that time, but when the temperature increases during the day, the air is able to carry more water vapor, thus reducing the amount of relative humidity.

As the air cools down under a specific pressure and the amount of permanent water vapor, it reaches a temperature that becomes saturated with it. This temperature is called the degree or dew point, but if the temperature is less than that, the water vapor begins to condense and the clouds, Dew, and the lower the air temperature for the amount of dew contained therein, the relative humidity increased. (Quora, 2018)

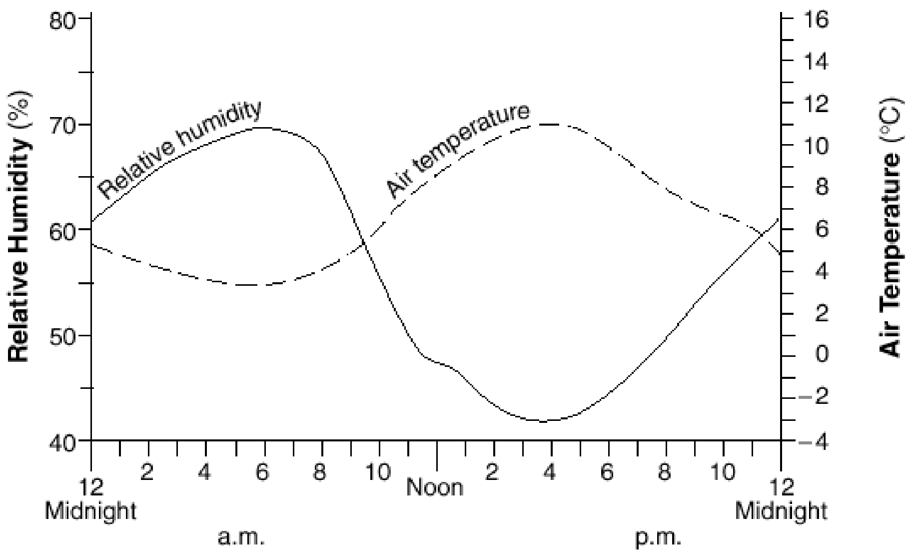


Figure 11. (Relationship between temperature and relative humidity, 2018)

10 TRADITIONAL SENSORS

A sensor is a device that detects and responds to certain types of input from the physical environment. Specific inputs can be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena.

The overall output signal is converted to a display that can be read by humans in the sensor location or electronically transmitted over a network to read or other processing.

Here are some examples of many different types of sensors:

This cyber-tronic looking sensor hides a secret behind its glimmering eye. Unlike most temperature sensors, this sensor measures infrared light bouncing off remote objects, so it can sense temperature *without* having to touch them physically. Simply point the sensor towards what we want to measure, and it will detect the temperature by absorbing IR waves emitted.

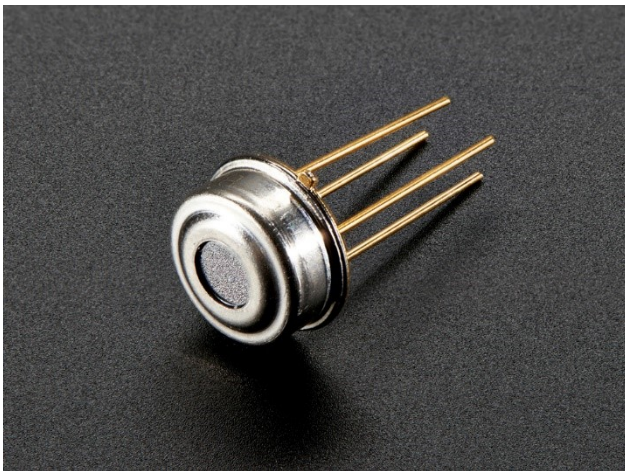


Figure 12. (Melexis Contact-less Infrared Sensor - MLX90614 5V, 2018)

The Parallax PIR Motion Sensor is a pyroelectric device that detects motion by measuring changes in the infrared (heat) levels emitted by surrounding objects. When motion is detected the PIR Sensor outputs a high signal on its output pin. For example, infra-red-light beam, ultrasound sound wave, high frequency electromagnetic wave. When someone enters the area the difference in reflection of light, sound or electromagnetic wave is detected.

Figure 13. (Parallax PIR Motion Sensor, 2018)

light dependent sensor (ldr) Photoresistor is a resistor which made of semi-conductor material, and the conductance changes with luminance variation. The photoresistor can be manufactured with different figures and illuminated area based on this characteristic. A photosensor detects the presence of visible light, infrared transmission (IR), or ultraviolet (UV) energy.

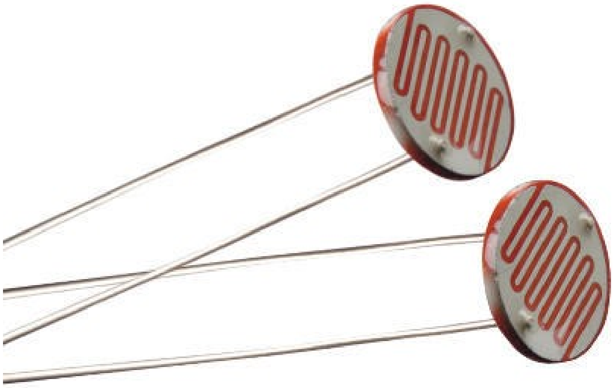


Figure 14. (Photosensor, 2018)

Today’s sensors are used almost everywhere. Radar guns bounce microwaves from speeding cars. A burglar alarm and photosensor may use to detect when a beam of light has been broken or may use ultrasonic sound waves that bounce of objects moving. Other sensors may still detect pressure (barometer) or chemicals (breathalyzers and smoke detectors).

Finders pin, which are used by carpenters to locate the wooden pins under the wall, may use magnets or radar. Wired gloves, which are transfer information about the position of the fingers. Are used in virtual reality environments. The car alarm may be only cheap shock sensor, which strong vibration will cause two metal surfaces to work together. (Definition of SENSOR, 2018)

11 ELECTRICAL CONDUCTIVITY OF SOIL

Soil electric conductivity depends on soil moisture content. Conductivity measurement can be very useful. If we would be able to measure change in conductivity we would be able to determine a change in moisture content.

There are two commercially available sensors to measure the soil electrical conductivity in this field. The types of sensors are contact or non-contact. The measurements of each of the sensor types gave equivalent results. (Virginia Cooperative Extension, 2018)

11.1 Contact sensor measurements

In this kind of sensor uses coulters as electrodes to conduct contact with soil and to measure electrical conductivity. In this approach, two or three pairs of coulters are installed on the toolbar, one pair provides electrical current into the soil (transmitting electrodes) while the other coulters (receiving electrodes) measure the voltage drop between them.

The electrical conductivity of the soil is recorded in the data recorder along with the location information. The global positioning system provides (GPS) the location of information to the data recorder. The contact sensor is most popular for precision farming applications because large areas can be mapped quickly, and it is least susceptible to outside electrical interference.

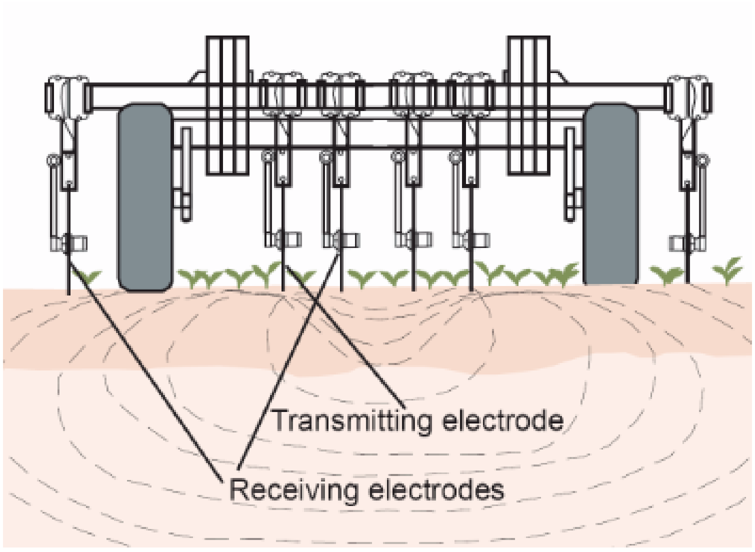


Figure 15. (Contact type EC, 2018)

11.2 **Non-contact sensor measurements**

Non-contact electrical conductive sensors operate on the principle of electromagnetic induction (EMI). Electromagnetic induction does not contact the soil surface directly. The device consists of a transmitter and a receiver coil, they are usually installed on opposite sides of the unit. The sensor in the device measures the resulting electromagnetic field that the current induction. The strength of this secondary electromagnetic field is proportional to the electrical conductivity of the soil.

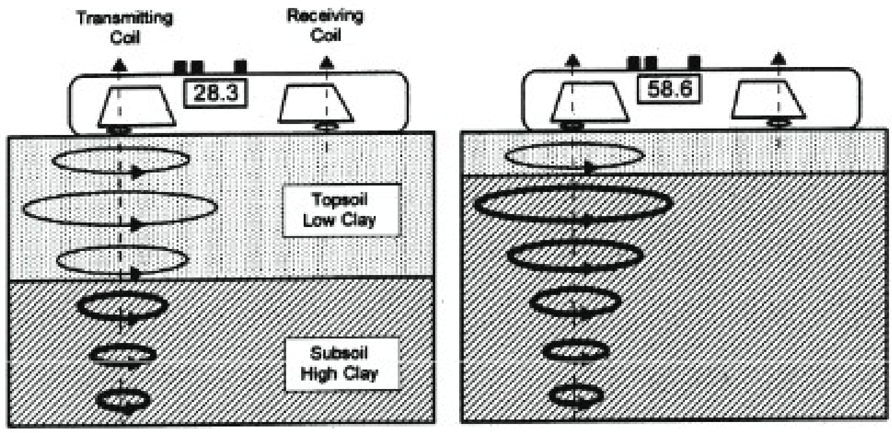


Figure 16. (Non-contact type EC, 2018)

12 USEFULNESS OF SOIL CONDUCTIVITY

The electrical conductivity of the soil varies depending on the amount of moisture retained by the soil particles. Sands has a low conductivity, silts have a medium conductivity, and clays have a high conductivity. As a result, electrical conductivity is strongly related to particle size and soil texture. (Virginia Cooperative Extension, 2018)

13 HUMIDITY SENSORS OPERATING PRINCIPLES

Humidity sensors are used in varying applications such as air conditioners, heating systems, and ventilation systems, they can be used in homes and office buildings. These devices, control humidity levels by measuring the humidity and air temperature and reporting relative humidity (RH) in the air. Their purpose is to ensure the maintenance of a constant temperature.

Humidity sensors contain a sensor mechanism that enables them to detect electrostatic changes in the air. The change is detected and converted into a digital reading, which displays the level of moisture in the air.

13.1 Different types of humidity sensors

13.1.1 Capacitive

These sensors measure the moisture levels by using the capacitor depends on the humidity. They are suitable for wide ranges relative humidity and condensation tolerance. Usually they are used these sensors in industrial and commercial environments.

13.1.2 Resistive

These sensors can measure the electrical change in devices such as conductive polymers and treatment substrates. Usually they are use theses sensors in residential and commercial environments.

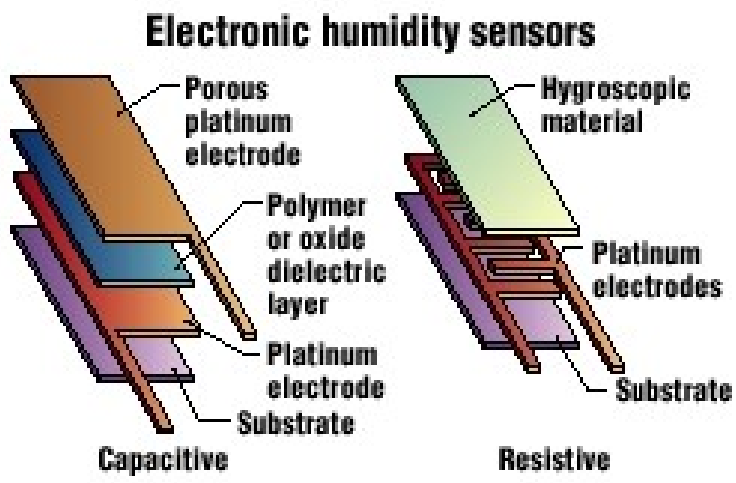


Figure 17. (Capacitive and Resistive, 2018)

13.1.3 Thermal conductivity

These sensors are suitable for use in environments that contain elevated temperatures. Usually they are measures humidity by calibrating the difference between thermal conductivity of dry air and wet air. This *DHT11 Temperature and Humidity Sensor* features a calibrated digital signal output with the temperature and humidity sensor complex. Its technology ensures the high reliability and excellent long-term stability. A high-performance 8-bit microcontroller is connected. This sensor includes a resistive element and a sense of wet NTC temperature measuring devices. (Different Types of Humidity Sensors - Switches International, 2018)

Figure 18. (DHT11 Temperature and Humidity Sensor, 2018)

14 SENSORS FOR SOIL MOISTURE

14.1 Mesh protected weatherproof SHT10

SHT1x including (SHT10, SHT11 and SHT15) is Sensation's family on the surface of the mountable relative humidity and temperature sensors. The sensors integrate sensor elements as well as plus signal processing on a small footprint and provide a fully calibrated digital output. The unique capacitive sensor element is used to measure relative humidity while the temperature is measured by a band-gap sensor.

The applied CMOSens® technology guarantees excellent reliability and long-term stability. Each sensor is smoothly coupled to an analog from 14 bits to digital converter and a serial interface circuit. This leads to superior signal quality, fast response time and insensitivity to external disorders. (EMC, electromagnetic compatibility)

SHT10 is based humidity / moisture and temperature sensor. The sensor is including a dual uses sensor module of Sensirion in encasing metal mesh sintered. The casing is weatherproof and will prevent leaking of water into the body of the sensor so as not to be damaging it, but it allows the air to pass through them so that can measure the moisture of outside.

While it is designed to be submersible in water, it is always best to avoid long-term over one hour at a time submersion, and it obviously would only give me temperature readings. For that, our metal-cased temperature sensors would be better. This sensor is best for simply placing outside for exterior weather sensing.

Moisture reading have 4.5 % accuracy, temperature reading is 0.5 % accuracy. A microcontroller is required to interface. Not wash the sensor after reflowing and must be dried according to the requirements of the datasheet.

The sensor is basically just a Sensirion SHT-10 with the four data power wires brought out so any SHT-1X code for a microcontroller will work. The sensor works with 3 or 5V logic. (SHT1x (RH/T) - Digital Humidity Sensor | Sensirion, 2018)

Figure 19. (SHT1x (RH/T) - Digital Humidity Sensor, 2018)

Table 2. Technical parameters

Parameters	value
Power supply voltage	3-5.5V
Temperature range	-40 + 123.8℃
Temperature measurement accuracy	$\pm 0.3 - 0.5$℃ @ 25 ℃
Moisture range	0-100%RH
Moisture measurement accuracy	$\pm 1.8 - 4.5\%$RH
Power	80μW (12 measurement, 1time/s)

Table 3. Interface specifications

Identification	Lead	Name	Comment
S	Yellow	SCK	Clock signal
+	Red	VDD	Power
-	Black or green	GND	Ground electrode
D	Blue	DATA	Data output

14.1.1 Testing sensor

This form shows the code, which I was used for the test sensor to get the result of sensor working. Calculate the humidity, temperature and dewpoint in the air, dewpoint does not include in my project. I used

Arduino IDE (Integrated Development Environment) software to upload code to the Arduino pro mini board as shown as code below:

```
#include <Sensirion.h>

const uint8_t dataPin = 10;

const uint8_t clockPin = 11;

float temperature;

float humidity;

float dewpoint;

Sensirion tempSensor = Sensirion (dataPin, clockPin);

void setup ()

{

Serial.begin(9600);

Serial.println("Starting Up");

}

void loop ()

{

tempSensor.measure(&temperature, &humidity, &dewpoint);

Serial.print("Temperature: ");

Serial.print(temperature);

Serial.print(" C, Humidity: ");

Serial.print(humidity);

Serial.println(" % ")

delay (5000);

}
```

14.1.2 Arduino Pro Mini

This board was developed for applications and installations where space is premium, and projects are made as permanent set ups. Small, available in 3.3 V and 5 V versions, powered by ATmega328P.

The Arduino Pro Mini is a microcontroller board based on the ATmega328P. It has 14 digital input / output pins (of which 6 can be used as PWM outputs), 6 analog inputs an on-board resonator, a reset button, and holes for mounting pin headers. A six-pin header can be connected to an FTDI cable or Sparkfun breakout board to provide USB power and communication to the board. The Arduino Pro Mini is designed for semi-permanent installation in objects or exhibitions. There are two version of the Arduino Pro Mini, one runs at 3.3V and 8MHz, and the other at 5V and 16 MHz. The Arduino Pro Mini was designed and is manufactured by Sparkfun Electronics. ("Arduino Pro Mini", 2018)

14.1.3 Technical specifications of Arduino Pro Mini are as follows:

- ATmega328 running at 16MHz with external resonator (0.5% tolerance)
- 0.8mm Thin PCB
- USB connection off board
- Supports auto-reset
- 5V regulator
- Max 150mA output
- Over current protected
- DC input 5V up to 12V
- On board Power and Status LEDs
- Analog Pins: 8
- Digital I/Os: 14

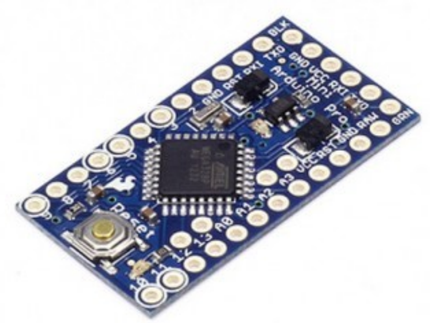


Figure 20. (Arduino Pro Mini, 2018)

14.2 **Method details**

The whole project was based on the Atmel platform, naturals I needed an Atmel board. I used an Atmel ICE board for this project. Then I need a board with Wisol BRKWS01 chip from Sigfox. I recommend is using the Sigfox breakout board BRKWS01 which I tested, and it worked without problems. To measure the moisture and temperature in the soil, I needed an appropriate sensor. I used the soil moisture and temperature sensor from Adafruit, which is based on the SHT-10 sensor from Sensirion. It was easy to use with Atmel as there was a dedicated library, so it was easy to interface this with my project.

First, I needed to connect the BRKWS01 chip to battery 3.6V and to the Atmel ICE board by using the AVR port, then Atmel ICE to the computer by micro USB. I need to connect the Tx, Rx, Vcc and GND pins of the BRKWS01 board respectively to Data, Clock, Vcc and GND wires of the sensor.

The soil sample which I bought from a super market, soil sample sack has the highest percentage of organic materials. Soil from outside it so difficult to take a specimen because it is freezing.

I brought a plastic pail and put the soil inside the pail. I inserted the sensor into the soil at a depth of about 30 cm to measure the amount of the moisture and temperature in the soil. I recorded the readings obtained from the sensor. The readings were between 15 minutes, because we can send messages to Sigfox cloud every 10 minutes.

So, I chose 15 minutes to give the transmitter data an opportunity to reach to the cloud every 10 minutes and to make sure the message was received into the cloud.

The Sigfox payload is limited to 12 bytes (excluding the payload headers). A device to base station message is broadcast by the device for approximately 6 seconds at a rate of 100 bits/s within the RCZ1 (the Europe region).

Sending our messages is easy, but what about receiving messages, Sigfox makes it easier to receive data from cloud service by the use the callbacks. Callbacks are a service that allows Sigfox to push an event to our server upon an event. For example, our device might send a Sigfox message upon an external trigger, I might want to be notified once this event had occurred. This would be the idea case to use callback.

14.3 **I2C**

The Inter-Integrated Circuit (I^2C) Protocol is a protocol designed to allow multiple “slave” integrated digital circuits (“chips”) to connect with one or more “master” chips. Such as the Serial peripheral Interface (SPI) they are designed only for short communications within a single device. Such as

Asynchronous Serialization Interfaces (such as RS-232 or UARTs), it only requires two signal wires to exchange information. (I2C - learn.sparkfun.com, 2018)

Serial communication is basically sending or receiving the data one bit at a time. Current computers generally process data in bytes or some of them are multiple. The byte contains 8 bits. The bit is basically either a logical one or zero. The expression of each character on this page internally as one byte. The serial port is used to convert each byte to a stream of ones and zeroes as well as to convert a stream of ones and zeroes to bytes.

The serial port contains an electronic chip called the Universal Asynchronous Receiver / Transmitter (UART) that is already switching. (Introduction to RS232 Serial Communication - WCSC, 2018)

14.4 I2C at the hardware level

14.4.1 Signals

Each I^2C bus consists of two signals SCL and SDA. SCL is the clock signal, and SDA is the data signal. The clock signal is always created by the current carrier master. Some slave devices may force the clock drop sometimes to delay the master sending more data or need more time to prepare data before the master attempts to clock it out. This is called “extension clock” and is described on the protocol page.

Unlike UART or SPI connections, the I^2C bus drivers are “open drain” which means that they can pull the corresponding signal low but cannot cause it to rise. Thus, there can be no competition for the carrier as one device attempts to push the line up while another tries to pull it down, eliminate the possibility of damage to drivers or excessive power dissipation in the system. Each signal line has a pull-up resistance to it, to restore the signal to the top when there is no device that confirms it is low.

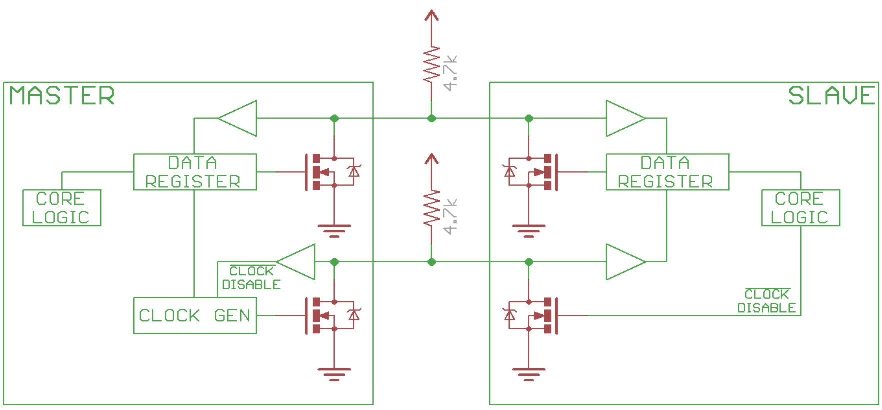


Figure 21. (pull-up resistances on the two communications lines, 2018)

14.4.2 Signal levels

In general, in a system where one device is in the high voltage of another, it may be possible to connect the two devices through the I^2C without any moving circuit on the level between them. This only works in some cases where the lower of the two-system voltage exceeds the high-level input voltage of the high voltage system, for example a 5V Arduino and a 3.3V accelerometer.

14.4.3 Protocol

Communication through the I^2C is more complex than with a UART or SPI solution. The signaling must comply with a specific protocol for devices on the carrier to identify it as valid I^2C connections. Fortunately, most devices take care of all our unique details allowing us to focus on the data we want to switch.

14.4.4 Basics

Messages are divided into two types of frame an address frame, the main master points to the slave to whom the message is sent, and one or more data frames. They are 8-bits data messages that are passed from master to slave or vice versa. The data are placed on the SDA line after the SCL is low, and samples are taken after the SCL line height. The time between the edge of the clock and data read / write is determined by the devices on the bus and will vary from chip to chip. (I2C – learn SparkFun, 2018)

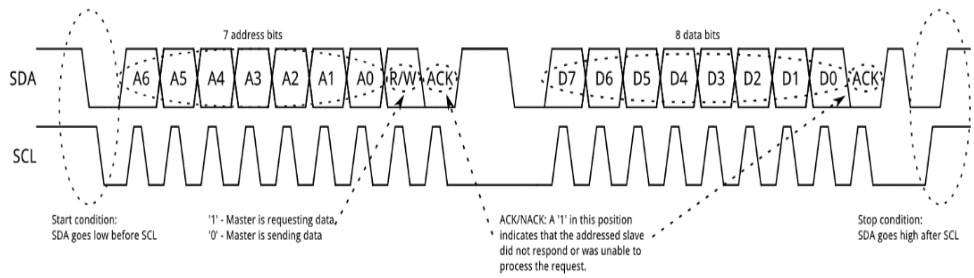


Figure 22. (7 address bits and 8 data bits, 2018)

14.5 **Atmel ICE**

Atmel-ICE is a powerful development tool for debugging and programming ARM Cortex-M based Atmel SAM and Atmel AVR microcontroller with on-Chip debug capability.

The Atmel-ICE unit requires that a front-end debugging environment Atmel Studio version 7.0 is installed on my computer.

The Atmel-ICE should be connected to the host computer using the USB cable provided, or a certified micro USB cable.

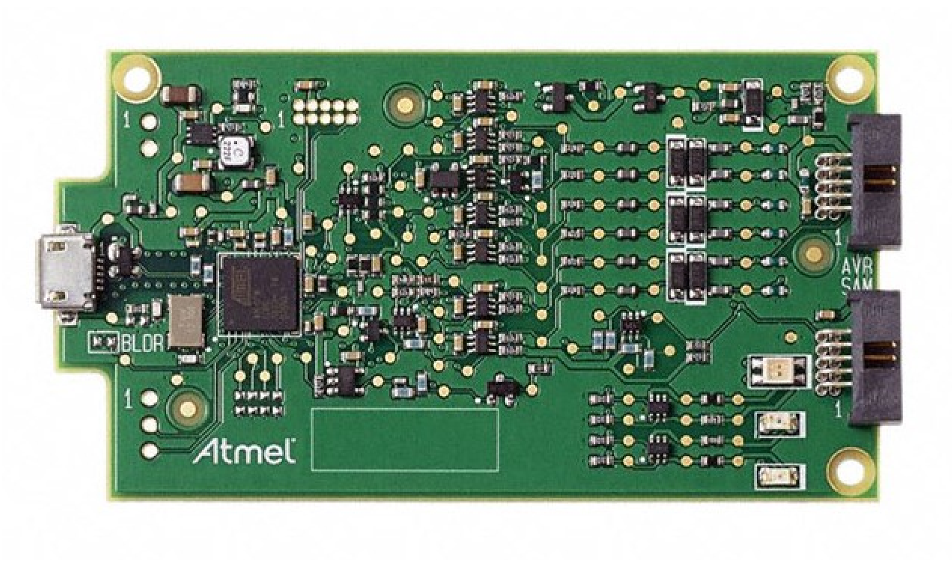


Figure 23. (Atmel-ICE Technology, 2018)

14.5.1 Connecting Atmel-ICE

The Atmel-ICE is equipped with two 50-mil 10-pin JTAG connectors. Both connectors are directly electrically connected, but conform to two different pinouts, the AVR JTAG header and the ARM Cortex debug header. The connector should be selected based on the pinout of the target board, and not the target MCU type for example a SAM device mounted in an AVR STK 600 stack should use the AVR header.

Various cabling and adapters are available in the different Atmel-ICE kits.

1. Atmel-ICE connection SAM
2. Atmel-ICE connection AVR

In this project I use the AVR connector to the Sigfox module radio by cable to send information to the module and then the module send data to Sigfox cloud and receive data from cloud to module radio.

14.5.2 Powering Atmel-ICE

The Atmel-ICE is powered by the USB bus voltage. It requires less than 100mA to operate and can therefore be powered through a USB hub. The power LED will illuminate when the unit is plugged in. when not connected in an active programming or debugging session, the unit will enter low power consumption mode to preserve my computers battery. The Atmel-ICE cannot be powered down in should be unplugged when not it uses.

14.5.3 AVR JTAG pinout

When designing an application PCB, which includes an Atmel AVR with the JTAG interface, it is recommended to use the pinout as show in the figure below. Both 100-mil and 50-mil variants of this pinout are supported, depending on the cabling and adapters included with the kit. (Technology, 2018)

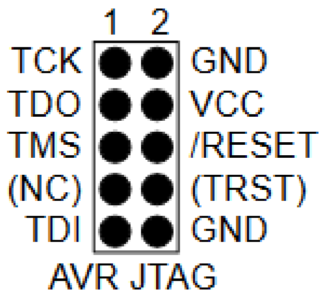


Figure 24. (AVR JTAG header pinout, 2018)

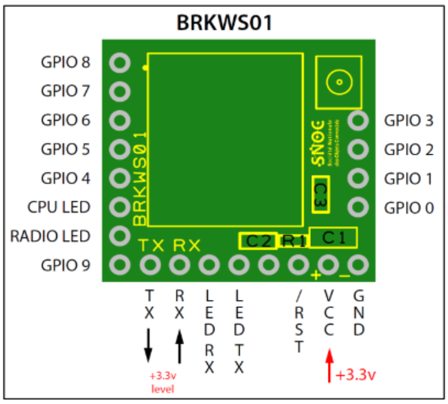
14.6 **Sigfox module radio**

The breakout BRKWS01 is a very small footprint Sigfox breakout board based on the Wisol SFM10R1 module (EMEA region). This board will enable me to integrate and use the Sigfox LPWAN (Low Power Wide Area Network) network into my IOT project design, providing simple data transmission feature.

The design of the breakout allows versatile usages from the development of my prototype to the mass production of my project. Indeed, the layout of input / output pin is such that I can use the standard module features with the breakout board position vertically as a single Inline package module (SIP). Therefore, the integration into my PCB design is facilitated.

The breakout board BRKWS01 is a based using the Sigfox verified Wisol module, ensuring reliable capabilities to communicate with the network. (BRKWS01, 2018)

14.6.1 BRKWS01 circuit diagram



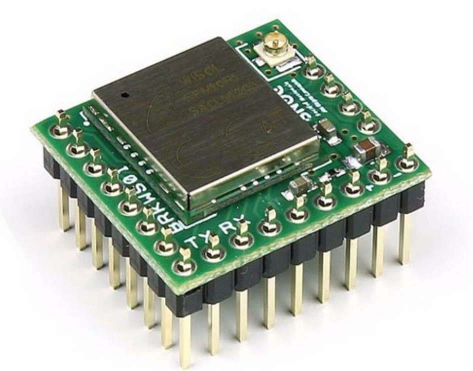


Figure 25. (BRKWS01, 2018)

14.6.2 Board specification

- Power supply: +3.3, 3.6V
- Tx current: 49mA
- Rx current: 15mA
- Communication: serial UART (Universal Asynchronous Receiver Transmitter)
- Protocol: AT commands
- Operating temperature: -30 to +85℃

14.6.3 BRKWS01 communication command

The module is controlled with serial AT commands sent on TX/RX pins. Below is the communication specification and AT commands to use. Serial communication: 9600 bauds, 8bits, 1 stop bit, no parity AT commands:

Table 4. (BRKWS01 details)

Communication test:	AT
Get Module ID:	AT$I=10
Get PAC code:	AT$I=11
Send a SIGFOX message:	AT$SF=XXXXXXXXXXXX (Hexadecimal value)
Send a SIGFOX message with downlink frame:	AT$SF=XXXXXXXXXXXX,1 (Hexadecimal value)

14.7 **Sigfox technology**

Sigfox has launched the world's first global internet of things (IoT) network to listen to the billions of objects broadcasting data, without having to create and maintain network connections. This approach is unique in the wireless connectivity, where there are no signaling overhead, compressed and improved protocol, and where objects are not connected to the network. Sigfox offers a software-based communication solution, where all the complexities of the network and computing are managed in the cloud, rather than on the devices. All together greatly reduces the energy consumption and costs of connected devices. The 140 messages per day are linked to maximum bandwidth occupancy allowed on the UNB to use Sigfox transmission characteristics, so 6 messages per hour, so we can send data every 10 minutes. (Sigfox Technology Overview | Sigfox, 2018)

14.7.1 Ultra narrow band

Sigfox uses 200 kHz of the publicly available and unlicensed bands to exchange radio messages over the air (868 to 869 MHz and 902 to 928 MHz depending on the region). Sigfox uses Ultra Narrow Band (UNB) technology combined with DBPSK and GFSK modulation. Each message is 100 Hz wide and transferred at 100 or 600 bits per second data rate depending on the region. Hence the long distance can be achieved while being very robust against the noise. (Radio Technology Key points | Sigfox, 2018)

14.7.2 Small payload

An uplink messages has up to 12 bytes payload and takes an average 2s over the air to reach the base stations which monitors the spectrum looking for UNB signals to demodulate. For a 12-byte data payload a Sigfox frame will use 26 bytes in total. The payload allowance in downlink messages is 8 bytes.

14.7.3 Downlink connectivity

Downlink service is a device driven to minimize energy consumption. It is up to the device to ask the network to get a downlink message.

14.8 **Connected Finland Sigfox operator**

Connected Finland and Connected Baltics are committed to operate a high quality and redundant network to serve our customers IoT solution needs. Within one-year quick ramp-up we have already reached most of population coverage in both countries, and we are determined to continue the network expansion. Our networks are part of global Sigfox network ecosystem, where all devices work seamlessly.

Connected Finland is operating nationwide, dedicated IoT-networks powered by global Sigfox-technology. Our network covers already 85 % of Finnish population and hundreds of global and local ecosystem partners are already utilizing our Low Power Wide Area Network technology in their IoT solutions. (Coverage - Connected Finland, 2018)

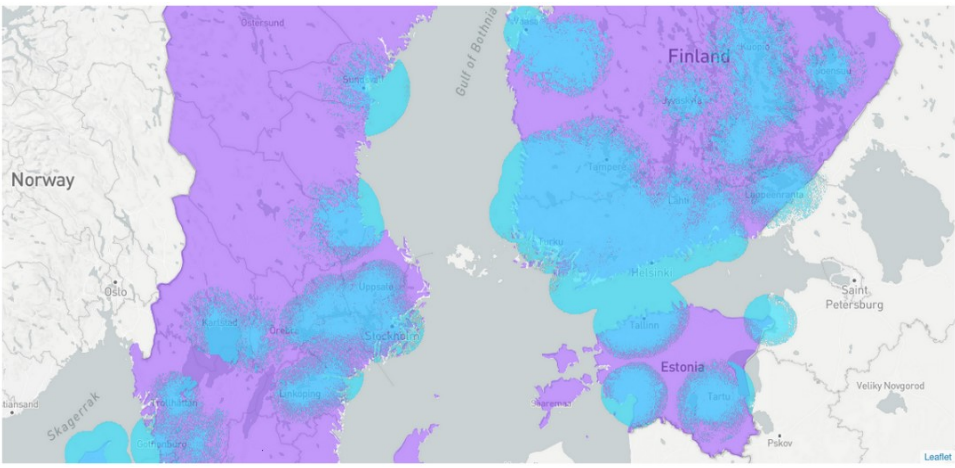


Figure 26. (Coverage - Connected Finland, 2018)

15 LPWAN TECHNOLOGY

LPWANs operate a lower coast with more power efficiency than traditional mobile networks. They can support a larger number of connected devices across a larger area. LPWANs can accommodate packet sizes from 10 to 1000 bytes at speeds up to 200 kbps. LPWANs long range varies from 2 km to 1000 km depending on the technology. Most LPWANs have a star topology, like a Wi-Fi network, connecting each endpoint directly to shared central access points.

15.1 Types LPWANs

LPWAN is not a single technology, but a group of variety of different low-power and wide area network technologies that takes many shapes and forms. LPWANs can use licensed or unlicensed frequencies and include proprietary or open standard options. Sigfox is one of the most widely deployed LPWAN networks today. Running over a public network in the 868 MHz or 902 MHz bands, (UNB) the Ultra Narrow Band technology only allows a single operator per country. While messages can be delivered over distance of 30-50 km in rural areas, 3-10 km urban areas and up to 1000 km in the applications of the site line, the package size is limited to 150 messages from 12 bytes per day. Packages in the downlink are smaller and are limited to four messages of 8 bytes per day. Data can also be sending to endpoints that are prone to interference.

Random phase multiple access, or RPMA is a proprietary from Ingenu Inc. although it has a shorter range (up to 50 km from the line of sight and with a 5 to 10 km invisible line), it offers better bidirectional communication than Sigfox. However, since it works in the 2.4 GHz band, it is prone to interference from Wi-Fi, Bluetooth and physical structure. Usually the power consumption is higher than other LPWAN options.

loRa is not licensed specified and supported by the LoRa Alliance, transmits in many GHz frequencies making them less prone to interference. A derivative of chirp spread spectrum (CSS) modulation, LoRa allows users to limit package size. LoRa is the Media Access Control (MAC) layer protocol that manages communication between LPWAN devices and portals.

Weightless SIG has developed three standards: the unidirectional Weightless-N, bidirectional Weightless-P and Weightless-W, it is also bidirectional and is operated from a non-user TV spectrum. Weightless-N and Weightless-P are often more popular options due to Weightless-W's shorter battery life. Weightless-N and Weightless-P bands operate in the 1 GHz unlicensed spectrum but also support the operation of the licensed spectrum using the narrow band 12.5 KHz.

Narrowband-IoT (NB-IoT) and LTE-M are both third Generation partnership Project (3GPP) standards that operate on the licensed spectrum. While they have similar performance to other standards, works on current cellular infrastructure, allow service providers to quickly add cellular Internet connections to their service portfolios. (LPWAN, 2018)

Other LPWAN technologies include:

- Green OFDM from GreenWaves Technologies
- DASH7 from Haystack Technologies Inc.
- Symphony Link from Link Labs Inc.
- ThinkPark Wireless from Actility
- Ultra Narrow Band from various companies including Telensa, Nwave and Sigfox
- WAVIoT

Figure 27. (How the LPWAN market shakes out - Rethink, 2018)

16 MEASUREMENT OF SOIL MOISTURE AND TEMPERATURE

16.1 Before drying

These records were every 15 minutes from the soil sample, I notice the moisture increasing readings from time to time, other thing the temperature is almost constant or change a little of bit shown in form below:

Table 5. (Moisture & Temperature readings before drying)

Moisture %	Temperature °C
79.25 %	20.86 °C

83.4 %	20.26 ℃
87.3 %	20.12 ℃
96.45 %	19.73 ℃
97.5 %	18.37 ℃
98.98 %	18.2 ℃
99.36 %	18.12 ℃
99.72 %	18.13 ℃
100 %	18.13 ℃

16.2 **After drying**

Noticeably the moisture decreases gradually from 100 % to the records. temperature records increase after drier as shown as in form below:

Table 6. (Moisture & Temperature readings after drying)

Moisture %	Temperature ℃
32.10 %	27.27 ℃
27.15 %	27.21 ℃
25.47 %	25.44 ℃
24.76 %	24.54 ℃
24.50 %	24.04 ℃
24.35 %	23.96 ℃
24.29 %	23.87 ℃

17 OVEN DRYING METHOD

Determination of the water content of a given soil by oven drying method, water content is expressed as the ratio of the weight of water to the dry weight of solid particle in a given soil mass it is expressed:

$$W = \frac{W_w}{W_d} \, x \; 100 \; \% \tag{14}$$

W_w = weight of water

W_d = dry weight of solid particles

Now we shall demonstrate the determination of water content of a given soil by a one drying method as per soil sample the apparatus required for conducting this practical includes:

- Three containers
- Sensitive scale with 1 g accuracy

- Oven drying 110 ℃ for 24 hours
- Soil sample
- Desiccator

Start with the experiment first of all obtain a clean and dry container and recorded a number of the container and weight the container and record the reading in the performer now I take the required quantity of giving the soil specimen.

Figure 28. Three containers

Crumble the specimen gently with fingers and place it loosely in the container, weight the container and record weight in the performer and the same thing to the rest.

Figure 29. Container weight before and after put soil

Now I must to maintain the temperature of the oven at 110 ℃ and I kept the specimen in the oven for 24 hours and then I take out the container with dried specimen.

Now I place it in a desiccator for bringing the specimen to room temperature and to avoid the absorption of atmospheric moisture, now I take container out and weight the container again and record the values.

Table 7. (Three containers weighed before and after soil sample)

Determination number	(1)	(2)	(3)
Container number	1	2	3
Weight of container W_1 (g)	190	189	201
Weight of container + wet soil W_2 (g)	220	210	230
Weight of container + dry soil W_3 (g)	206	201	219
Weight of moisture $W_2 - W_3$ (g)	14	9	11
Weight of dry soil $W_3 - W_1$ (g)	16	12	18
Water content $W = \frac{W_2 - W_3}{W_3 - W_1}\ x\ 100\ \%$	87.5 %	75 %	61.11 %

W = water content

W_1 = weight of container (g)

W_2 = weight of container + wet soil (g)

W_3 = weight of container + dry soil (g)

$W_2 - W_3$ = weight of moisture (g)

$W_3 - W_1$ = weight of dry soil (g)

$$W = \frac{W_2 - W_3}{W_3 - W_1}\ x\ 100\ \% \tag{15}$$

$$W_{n1} = \frac{220 - 206}{206 - 190}\ x\ 100\ \%$$

$$W_{n1} = 87.5\ \%$$

$$W_{n2} = \frac{210 - 201}{201 - 189}\ x\ 100\ \%$$

$$W_{n2} = 75\ \%$$

$$W_{n3} = \frac{230 - 219}{219 - 201}\ x\ 100\ \%$$

$$W_{n3} = 61.11\ \%$$

Average water content W_A:

$$W_A = \frac{W_{n1} + W_{n2} + W_{n3}}{3}$$

(16)

$$W_A = \frac{87.5\ \% + \ 75\ \% + 61.11\ \%}{3}$$

$$W_A = 74.54$$

18 CONCLUSION

Determination of soil water content is to show gravimetric measurement of soil water content is based on removal of water from soil sample. Water is removed by heating the soil sample at 110 degrees to evaporate the water from soil sample. The amount of water removed from the soil sample is determined and used to calculate soil moisture content. The simplest method to determine water content removed is by measurement of loss of weight of the sample.

The work of the basic sensor is to measure the relative humidity and temperature in the air. When we want to measure moisture and temperature in the soil sample, the sensor measuring relative humidity in the air inside the soil sample. Relative humidity of the air sample inside the soil is related to water content of the soil.

So, water content affects on the sensor readings. Water content and air inside of the soil sample must take into consideration. When water content increases, it will affect on the readings and it depends on the area and place of the soil.

In my measurement the temperature of the soil sample was not stable. The evaporation of water out of the soil sample decreased the temperature of the soil. This is because the evaporation takes power and the power is taken from the heat of the soil sample.

In the experiment, determination of water content in a soil sample had the highest water content average with 74.54 %.

In the beginning, in temperature 21 degrees the sensor got some humidity inside and showed a value 80%. The same moisture stayed inside the sensor. But when the sensor temperature decreases to 18 degrees the same water content in the air corresponded 100% humidity.

Finally, moisture and temperature will be different from winter to summer and from morning to midnight all these options affect the soil. But when we are using SHT-10 it will help us to minimize the effects in the soil and give us the perfect readings so, it will be improving the soil in the future.

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